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Energy situation, potential and application status of small-scale hydropower systems in Malawi

Chiyembekezo S. Kaunda *

Department of Mechanical Engineering, University of Malawi, Private Bag 303, Chichiri, Blantyre 3, Malawi

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ABSTRACT

Sustainable energy is required for any national development. This paper has reviewed and documented energy situation and small-scale hydropower potential and application status in Malawi. The country's energy sector is dominated by traditional forms of biomass. Level of modern forms of energy supply is low. In particular, electricity supply is unreliable and small in capacity. Decentralised energy supply systems like small-scale hydropower are some of the recommended energy projects for developing countries.

The paper adds knowledge on small-scale hydropower in Malawi. The study has reviewed Government reports and other documents. Informants were also consulted. Information from documents and informants was confirmed through site visits.

The analysis of the small-scale hydropower potential sites indicates that the country has considerable potential for decentralised hydropower generation, which if fully exploited, can contribute to the country's electricity and power supply especially for rural electrification. Most of the identified potential sites are located in the northern parts of the country. From the information on the assessed sites, a proven potential of 7.6 MW can be harnessed. An inventory of small-scale hydropower systems shows there is an installed capacity of 5.8 MW with most of the plants not functioning due to various reasons. Challenges and opportunities towards popularisation of the technology have been identified and discussed.

Contents

* Tel.: +265 1 870 411; fax: +265 1 870 578.
E-mail address: skaunda@poly.ac.mw

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1. Introduction

Energy is quoted as one of the ingredients in the social and economic development process of any nation and especially so for the developing countries [1,2]. All aspects of development—social, economic, and environmental—including livelihoods, access to water, agricultural productivity, health, population levels, education, and gender-related issues are affected by energy. In developing countries, improvement in the quality and quantity of energy services is necessary in order to meet the Millennium Development Goals [2]. In developing countries where small and medium enterprises (SMEs) are booming, access to electricity can increase productivity levels through use of efficient electricity powered tools that replace human labour. Access to electricity also increases productivity through lengthening working time and business time (it is possible to work and do business at night because of provision of light).

Business in rural growth centres, small-scale mining and agro-based processing activities are some of the areas where electricity can be used for income generating purposes. However, in most of the developing countries, especially in sub-Saharan Africa (except South Africa) such development activities are hindered by acute shortage and unreliability of the already small electricity supply and extremely low popular electricity access levels in rural areas. In most of the sub-Saharan Africa countries, there are disproportionately large gaps between urban and rural electrification levels: an indicator of social inequality. The poor state of electricity sector in sub-Saharan Africa is well documented by Eberhard and others [3]. Decentralised (off-grid or stand-alone) electricity generating plants are considered as some of the options for rural electricity supply unlike grid extension from central electricity generating stations Kaundinya and others [4]. The latter is prohibitively expensive and technically challenging to implement considering the long electricity transmission distances from generating stations to load points, difficult terrain with poor or no access roads and sparseness of rural human settlements.

The decentralised power system is characterised by generation of power nearer to the power consumption points, focusing mainly on meeting local energy needs (remote settlement, rural town or localised industry). For this reason, this power supply system is usually small scale. Because of short distances between generation point and load points, decentralised power systems are more efficient than the centralised (grid-based) electricity supply system. The decentralised power system can function either in the presence of grid, where it can feed the surplus power generated to the grid, or as an isolated power system. The latter has localised grid network linking the generating station to load points. Further, a decentralised power system is also classified on the basis of type of energy resources used: renewable and fossil fuel. In sub-Saharan Africa, fossil fuel powered decentralised power systems (gensets) can be expensive to run because of high pump price of oil and costs of transporting oil to the power stations. A genset power system would not be appropriate in areas without access road. Therefore it would really be useful to promote renewable energy power decentralised power systems in such areas. It is a question of mapping the important renewable energy resources for electricity generation at national level so as to inform the type and design of decentralised power systems. Small-scale hydropower (SHP) systems are recommended for decentralised power supply because of their robustness and assurance of availability of firm power.

Promotion of decentralised power supply seems to be one of the realistic ways of increasing the electricity generating capacity incrementally in a sustainable manner for most of the sub-Saharan African countries that are associated with economic challenges. Decentralised energy systems can trigger economic growth and social development to an off-grid community and therefore play a very central role in the rural economic growth and development plans. Studies have affirmed this fact [5,6]. For example, Kirubi et al. [6] conducted a detailed case study on the Mpeketoni Electricity Project a community-based, diesel-powered micro-grid system in rural Kenya and they concluded that access to electricity, in conjunction with complementary infrastructure such as markets, roads, and communications, contributed to increased productivity in two key economic sectors of rural livelihoods namely SMEs and agriculture [3]. Not only in Kenya, but in other developing countries like Nepal, decentralised energy systems have brought economic and social development [7].

Further, if localised energy resources are utilised for electricity generation, the decentralised power systems can provide a more reliable rural electricity supply and provide a direct source of income for the community. For example, the use of agricultural and forest wastes, as well as other biomass resources for electricity generation decreases the dependence on imported fossil fuels and can provide income to local communities derived from biomass collection and transportation. The technical requirements to design, manufacture and manage the decentralised power systems create local techno-entrepreneurships opportunities such as in Nepal for SHP systems (Nepal). Renewable energy decentralised power systems such as the SHP systems are environmentally benign power supply technologies and are not associated with gaseous emissions. Such technologies are attractive for carbon trading such as the Clean Development Mechanism (CDM) of the United Nations Convention of Climate Change (UNFCCC).

Small-scale hydropower (SHP) is a robust renewable energy technology that generates mechanical power and electricity or both at the same time. In some countries like India, apart from generating power to remote off-grid areas, SHP is one of the clean energy technologies for carbon trading under the CDM [8]. Currently, the SHP technology is not new to Malawi and the rest of sub-Saharan countries. Installed SHP systems at some missions and tea estates date back to so many years ago, having been installed there by the early European missionaries and tea planters as the case with Malawi, Kenya and Tanzania [9]. Despite having significant SHP potential, SHP as a decentralised energy technology is not widely applied in sub-Saharan Africa as compared to other regions such as South East Asia and South America. In Malawi, focus on decentralised renewable energy systems by the government and other development partners has been on solar PV and very little on wind, and as a result there is limited information on potential and utilisation of small scale hydropower in the country. The SHP information available is sketchy, in scattered form and not in a position to be used as a reference document for energy researchers, policy and other stakeholders who may want to work in the field of SHP in Malawi.

The objective of this study is to investigate the potential and application status of the small-scale hydropower systems in Malawi. To do this, the general national circumstances and energy situation is provided to set a datum on which to describe the position of SHP in the Malawi's energy sector. The purpose of the study is to document information pertaining to SHP systems as alternative decentralised sources of energy supply in Malawi.

Specifically, the study attempts to

- Analyse energy situation in Malawi.
- Analyse the small scale hydro-potential in Malawi.
- Analyse levels of small scale hydro-applications in Malawi.
- Analyse challenges and opportunities to application of small scale hydro-systems in Malawi.

This study on energy situation, potential and application status of small-scale hydropower systems in Malawi contributes to the knowledge base on the application of renewable energy systems in the country. The study provides an inventory of potential sites and status of installed systems. A number of challenges and opportunities pertaining to uptake of small-scale hydropower technology are listed and discussed. It is possible, considering the nature of sources of information available, that the study may not cover every salient detail of SHP systems in the country, but it forms a basis upon which to start improving the data for the betterment in informing the relevant stakeholders in the SHP field. Therefore, if readers identify misplaced information and other areas that may require further information, then these deficiencies must energise the interested ones for further research and investigation in the SHP sector in the country.

This paper has been organised in sections as follows: Section 1 gives the introduction to the main purpose of the paper: general issues concerning energy and development have been presented with special emphasis on decentralised energy in sub-Saharan Africa region where Malawi is found. Section 2 states the methodology used. Malawi's national circumstances in terms of social and economic development, geographical description and climate have been discussed in Section 3 to provide a background for the discussions on the general energy situation and SHP status in the country. Section 4 presents the comprehensive overview on energy situation in Malawi. Section 5 discusses the SHP technology basics to inform the reader who may not be conversant with the technology so as to appreciate the following discussions on SHP potential and status for Malawi which is given in Section 6. The paper concludes the findings and makes some recommendations in Section 7. References are found in the last section.

2. Methodology

This paper is like a pioneering work on documenting and presenting information concerning SHP on potential and status in a way suitable for various stakeholders who may want to conduct research on and promote SHP energy projects in Malawi. Firstly, in 2010 while in Malawi, some key people were asked about the state of SHP so as to generate a skeleton of facts about the technology in the country. It then became evident to the author that the SHP is one of the most important renewable energy for decentralised electricity supply in the country. Then a desk study was conducted from a list of literature that was gathered so as to put together and interpret documented information on SHP including the SHP resource assessment studies, installed SHP units, challenges and opportunities. A list of key literature was obtained from the Government of Malawi in form of publications and reports. Supporting information for the desk study was obtained from published journals and other online reports. Consultations involving interviewing key informants and site visits were made to complement and to try to validate the information obtained from literature and informants. The key informants during the interviews were two energy officers from the Department of Energy Affairs (DoEA), a generation engineer from the Electricity Supply Commission of Malawi (ESCOM), an official from the Mulanje Renewable Energy Agency (MuREA), an official from Testing and Training Centre from Renewable Energy Technologies unit (TCRET) at Mzuzu University, energy lecturer (and consultant) at The Malawi Polytechnic (a constituent college of the University of Malawi) and an official from Lujeri Tea Estate in Mulanje. Site visits to some SHP installations were also carried out to validate information from literature and experts.

3. Malawi: National circumstances

3.1. Social and economic description

Malawi is a sub-Saharan African country with a population of 13 million in 2008 with an average annual growth rate of 2.8% [10]; in 2012 the population was estimated by the World Bank to be about 15 million [11]. The land area is about 95,000 km^2 (refer to the following geographical description on Section 3.2), giving an average estimated population density of 160 people per km^2 in 2012. The proportion of the rural population is about 85%. The population density is relatively large comparing to other countries in Africa; however the population is not evenly spread across the country: the Southern and Central regions are relatively densely populated as compared to the Northern Region. The country, like most of sub-Sahara African counterparts, is among the low income countries with poverty level around 50% [11]. In 2011, the GNI per Capita (Atlas Method) was 360 US$, life expectancy was 54 years, 80% of the rural population had access to improved water source [11]. The country is relatively narrow in width but longer in length; this has advantage in terms of road access to various parts of the country. In 2010, the roads network in Malawi comprised of 15,500 km of public road and 9478 km of undesignated community roads [12].

The economy of Malawi is relatively small but there are policies and programmes to improve the economic status of the country. According to the Malawi's Vision 2020, a long-term development perspective launched in the late 1990s, the country aims to be a technologically driven middle income country by the year 2020. The Vision 2020 has been translated into medium term development strategies, which began with the Malawi Poverty Reduction Strategy (MPRS) in 2002 covering a period of 3 years (2002–2005). The MPRS came to an end in 2005 and was replaced by the Malawi Growth and Development Strategy (MGDS) to cover a period of 5 years [13]. The first period of MGDS was from 2005/2006 to 2010/2011 financial year. The second MGDS is effective from 2011 upto the year 2016. The MGDS is the overarching policy document that guides the government and developing partners in achieving the country's Vision 2020 and the Millennium Development Goals (MDGs). Issues of sustainable energy generation and supply, integrated rural development, irrigation and water development, natural resources and environmental management are clearly given due attention as some of the priority areas in both MGDS documents so as to stimulate and support the economic growth. Relevance of decentralised renewable energy power generation systems such as small-scale hydropower plants in the realisation of MDGS objectives is therefore evident. For example, the SHP system can be applied to support income generation activities/services especially in the sectors of tourism, small scale mining, agro-processing and other SMEs in the designated rural growth centres.

Malawi is basically a consuming and an agro-based economy, the main cash crops being tobacco, tea, sugar, coffee and cotton. Within the first MGDS period (MGDS I), it is reported that the Malawi's economy grew steadily by an average of 7% per annum from 2006 to 2010 [14]. In the MDGS I, the country experienced a diversified and inclusive growth: significantly from the mining

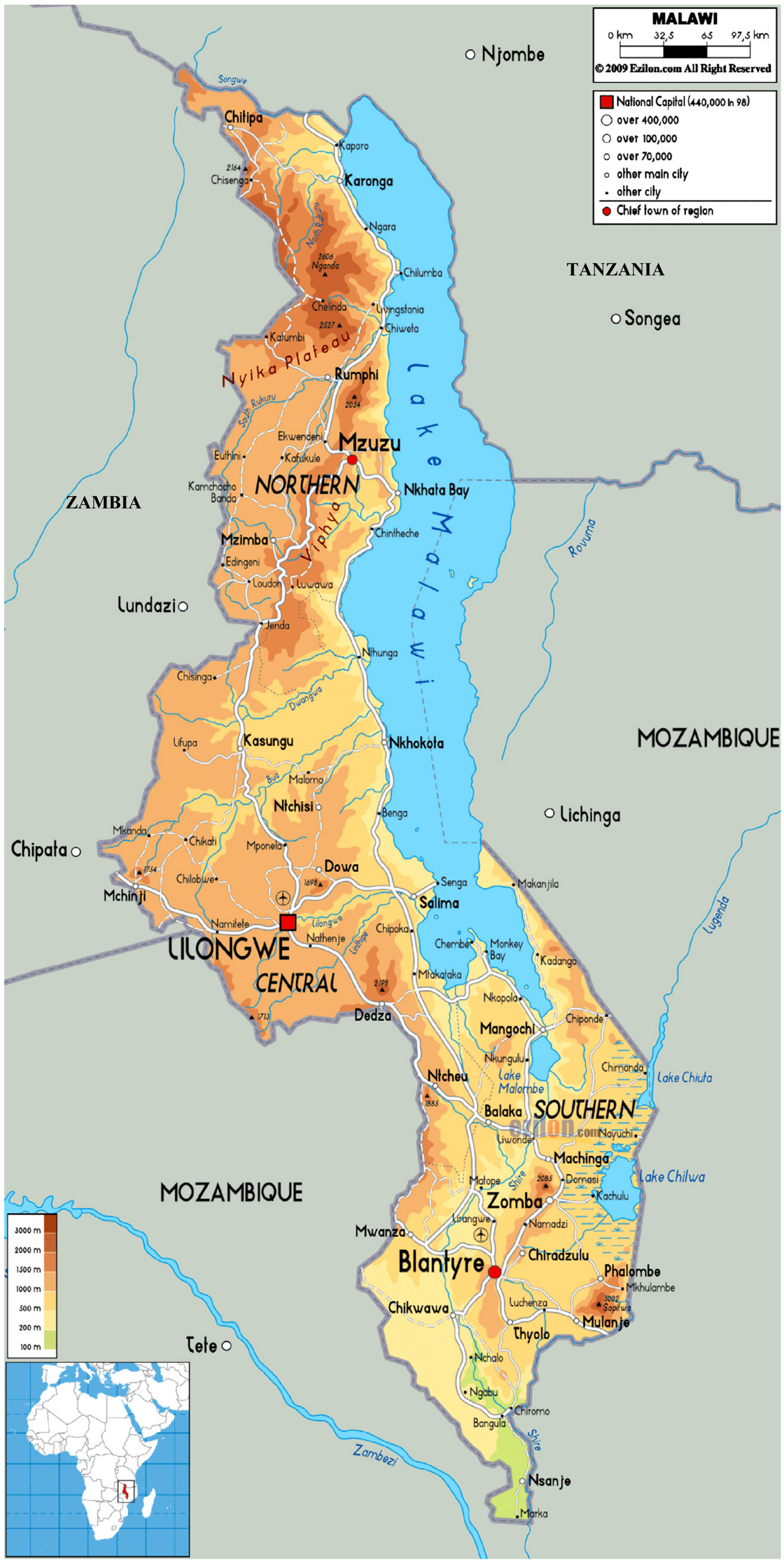


Fig. 1. Physical Map of Malawi, insert is map of Africa with Malawi highlighted *Source*: http://www.ezilon.com/maps/africa/malawi-physical-maps.html

sector [14]. In 2009, a relatively large scale uranium mining project was commissioned at Kayelekera in Karonga District. The Kayelekera mining (by Paladin Africa), by itself, is reported to have contributed an average of 7% of the country's GDP and it is expected to contribute more over its life span as the uranium production and international price improve [14]. Limestone in Kasungu District and coal in Rumphi District are other mining projects in the country. In the MGDS II, one of the priority areas is on boosting the agro-based income through expansion and commercialisation of mechanised irrigation farming on arable land that is in the vicinity of Lake Malawi, small lakes and important rivers. This programme is known as the Malawi Green Built Irrigation Initiative (GBI). The government of Malawi has committed itself to offer land (amounting to at least 1 million ha) to local and international investors for the GBI [15]. The MDGS II also focuses on mining activities to significantly contribute to economic growth. Exploration and mining licences have already been issued to some of rare metal sites. For example, the licence for Niobium, Uranium and Zirconium mining at Kanyika in Mzimba District has been issued to Globe Metals and Mining Company of Australia. For the interested readers, the environmental impact assessment draft report of the proposed Kanyika rare metals mining project (to start in 2015) can be accessed from the company webpage [16]. There are also some small-scale mining activities involving gemstone, limestone, stone aggregates and others. For further information in mining in Malawi, the reader may refer to a publication on mineral industry in Malawi by Ref. [17].

The current economic indicators for Malawi are still low, but it is the view of the author that from the ongoing and planned economic development programmes, the economic outlook for the country looks promising. Interventions in reducing population growth rate can be some of the ways of reducing poverty levels and increasing wealth per capita. It can also be stated that the sustainable interventions in energy sector are important ingredients for all of the economic development projects in the country.

3.2. Geographical description of Malawi

Malawi is a sub-Sahara African country located south of the equator between latitude 9°22' and 17°7' south and between longitudes 32°40' and 35°55' east [18]. Malawi is geographically located in the south-eastern part of Africa and is bordered to the north and northeast by the United Republic of Tanzania, to the west by the Republic of Zambia and to the southwest and east by Mozambique (Refer to Fig. 1). The country has a total area of 118,483 km^2 of which 94,275 km^2 is land and 24,208 km^2 is water [18]. Lake Malawi stores the bulk of surface water resources with an average storage of 90 km^3 at a mean level of 474 m above sea level and the total storage volume of the lake is 7725 km^3 [19]. The annual surface water resources yield on the land is 13 km^3 and predominately drains into Lake Malawi and the Shire River [19]. Other important surface water sources are small lakes, lagoons marches and rivers. Important rivers are Songwe, North Rukuru, South Rukuru, Kasitu, Dwangwa, Bua, Linthipe, Bwanje, Shire and Ruo. Shire River is the only Lake Malawi outlet. Major rivers are perennial but due to climate variation/change, seasonal rainfall patterns are changing causing some small rivers which were once perennial to become dry during the dry season. Malawi installed electrical power capacity is almost wholly hydropower and the power stations are located in the Shire River in a cascade arrangement. This implies that Lake Malawi is a strategic resource for power generation in Malawi.

About 75% of the land surface is plateau between 750 m and 1350 m above sea level. Highland elevations rise to over 2440 m in the Nyika Plateau in the north of the country and to over 3000 m Sapitwa on Mulanje Mountain (southern part of Malawi) [18]. The lowest point is in the southern border with Mozambique in Nsanje District, where the Shire River approaches its confluence with the Zambezi at 37 m above sea level [18]. Refer to the Malawi physical map in Fig. 1.

3.3. Malawi's climate

Traditionally, the Malawi's climate is referred to as subtropical with seasonal weather pattern. The warm-wet season stretches from November to April, during which 95% of the annual precipitation takes place [20]. A cool, dry winter season is from May to August with mean temperatures varying between 17 and 27 °C, with lowest temperatures falling between 4 and 10 °C [20]. The highest temperatures occur at the end of October or early November. The coldest months are June and July. Highest temperatures are recorded in the Shire Valley while the lowest are recorded over the high attitude areas particularly the Shire Highlands, the Viphya and Nyika plateaux, Dedza and Mulanje mountains and other high-altitude areas [20]. The Malawi's climate is strongly influenced by its position within the sub-continent in relation to the pressure and wind systems of the Southern Hemisphere [21]. In terms of rainfall, changes in the distribution of rainfall take place in response to the movement of the Inter-Tropical Convergence Zone-ITCZ [18]. The annual mean rainfall is between 725 and 2500 mm [20].

Rainfall grid for Malawi shows that the amounts and patterns of rainfall closely correlate with relief, such that highlands and escarpment areas experience greater precipitation than the low lying and rain shadow areas. Mulanje and Zomba mountains in the Southern Region and Nyika and Viphya plateau in the Northern Region are the prominent highland areas in Malawi with high rainfalls in the excess of 1800 mm annual rainfall while the low lying areas such as the Shire Valley and the plateau regions receive low rainfall [22].

Despite lack of comprehensive research on Malawi's climate system, the country's climate seems to be changing based on the anecdotal pieces of evidence. The onset and duration of seasons are no longer predictable in the country. The trends in the spread of diseases like malaria and diarrhoea are reported to correlate well with increase in temperatures and this may be attributed to issues of climate change and climate variability [21,23]. The observed increase in frequency and magnitude of extreme weather events such as hailstorms, floods and droughts are viewed as impacts of climate change in Malawi [21]. However, compressive research is needed to inform our knowledge on the relationship between these observations and climate change in the country.

4. Malawi's energy situation

4.1. General description

The Malawi's energy sector is made up of biomass, liquid fuels, coal, electricity and renewable energy sub-sectors. In Malawi, renewable energy sub-sector includes liquid biofuel, wind, solar and small scale hydropower systems: biomass fuelwood and large scale hydropower are not included. It is a question of defining 'renewable energy' and the question whether biomass fuelwood and large scale hydropower are elements of renewable energy sector may debatable. However, if biomass fuelwood is harvested from sustainable sources, then it becomes a renewable energy. Hydropower is regarded as a renewable energy whether large scale or smaller scale by some organisations like the International Energy Agency (IEA) possibly because the fuel (energy in running water) is derived from an endless process (hydrological cycle). If hydropower projects destroy environment and/or emit GHGs, then

they may be regarded as unsustainable and therefore not elements of ‘renewable energy’. However, hydropower projects encompass environmental and social mitigation measures which if they are well prepared and executed, hydropower can be a large and sustainable source of renewable energy.

Characterising the national energy sector provides some indicators for understanding the economic and social growth levels of the country. In fact, the IEA has come up with an Energy Development Index (EDI) in order to understand the role of energy in human development. The EDI is computed from the average of four indicators on per capita commercial energy consumption, per capita electricity consumption in residential (household) sector, share of modern fuels in household sector and share of population with access to electricity. The interested reader is encouraged to refer to IEA for further information on EDI [24]. The characterisation of the energy sector requires active data on energy usage. Finding such data is a big challenge for Malawi, especially in the household sector, because there is no agency responsible for collecting and recording energy usage data in the sector. In such situations, recourse to data estimation using surveys and other validated models become the alternative options. In the analysis of the energy sector in Malawi, the 2008 biomass surveys done during the formulation of biomass energy strategy [25] and study by Openshaw in 2010 [26] provide authoritative information on energy usage and supply in the country.

The Openshaw (2010) study revealed that in 2008, the annual energy consumption for Malawi was 11.5 GJ (3167 kWh) per capita, corresponding to an absolute consumption of about 150 TJ (refer to Table 1). The major energy consuming sectors are household, industry, transport and service. As, can be seen from Table 1, household sector is the major energy consumer (over 80%); the income generating/supporting sectors: industry, transport and service have very low shares of energy consumption. The dominance of household sector in the energy sector is typical for the rest of less industrialised sub-Saharan African countries except South Africa [27]. Biomass is the major source of primary energy supply in Malawi, providing 89% of the total national energy demand: the remaining 11% come from petroleum (6%), electricity (3%) and coal (2%), as can be seen in Table 1. Biomass is also seen as the dominant energy consumed within each energy consuming sector except in the transport sector (refer to Fig. 2): it provides 98% of energy consumed in the household sector; industry (55%), service (27%) and transport (5%, mainly from ethanol that is blended with petrol).

The absolute value of commercial energy consumed (coal, electricity and petroleum) was about 40 TJ representing a per capita consumption of 3 GJ. As can be seen in Table 1, commercial biomass (traded charcoal and fuelwood excluding commercial crop residues like bagasse) constituted more than half (56%) of all commercial energy consumed. Electricity contributed only 10% of the total commercial energy demand. This is different from the national electricity access rate because the electricity access rate is the percentage of households that have access to electricity in a certain area.

Fig. 2 also shows that the share of modern fuel consumption in the household sector is extremely low (2%): one of the indicators in determining the energy development index of the country, as stated earlier on. It is further seen that electricity is not the dominant energy consumed in every sector, the sector in which

Table 1
Estimated final energy consumed by sector and fuel in 2008 in Malawi. Units: Terajoules—TJ (TJ = 10^{12} Joules). Data adapted from Openshaw [26].

Fuel energy consuming sector	Biomass	Coal	Petroleum	Electricity	Total	Share = Total sector consumption/total consumption
Household	122143	0	644	1724	124,511	83%
Service	419	167	535	457	1578	1%
Industry	10,135	3337	3001	1927	18,400	12%
Transport	270	14	5407	34	5725	4%
Total	132,967	3518	9587	4142	150,214	
Fuel demand/total demand	89%	2%	6%	3%	100%	
Commercial energy consumption	22,284	3518	9587	4142	39,531	
Commercial (%) of total consumption	56%	9%	24%	10%		

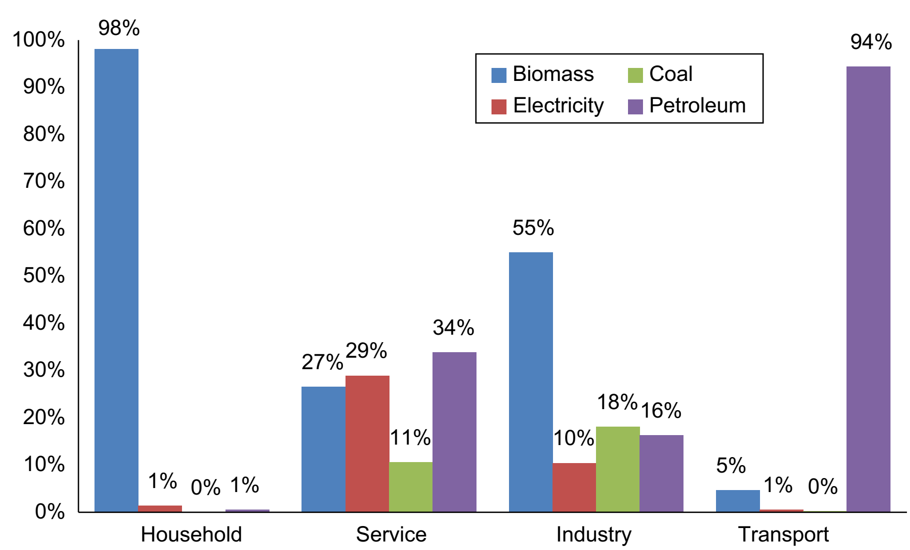
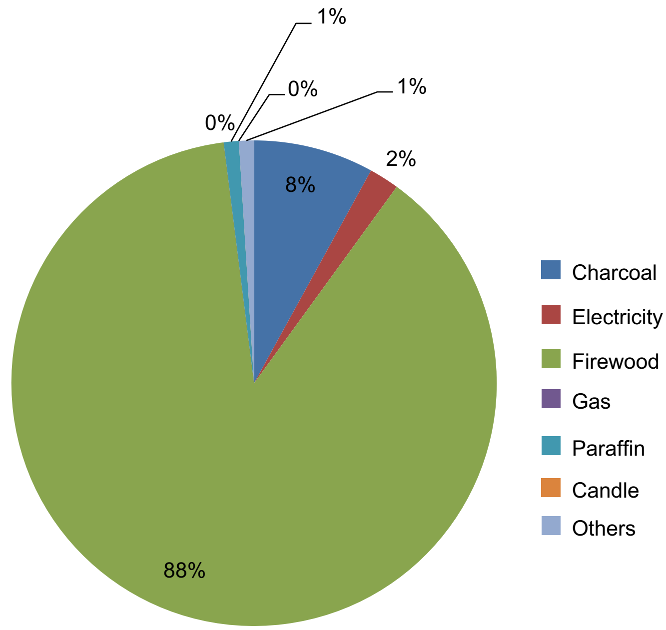


Fig. 2. Percentage share of sources of energy consumed within each sector, as constructed from data provided in Table 1. The vertical axis is the percentage share of energy consumed in that sector.



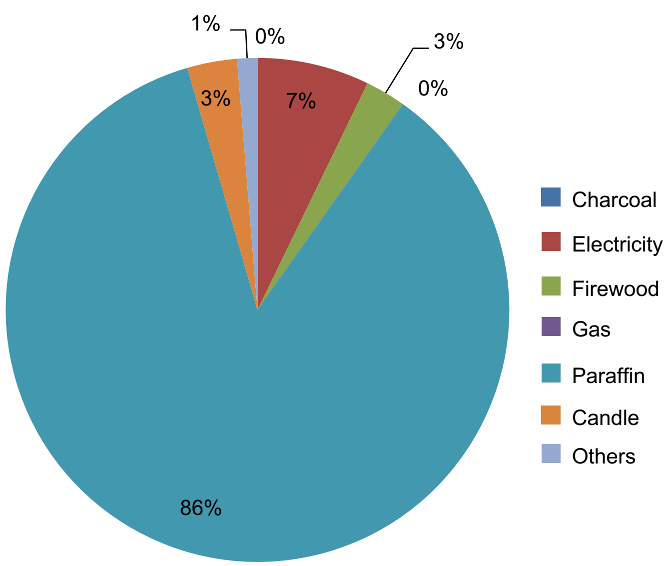


Fig. 3. (a) Sources and percentages of household using the fuel of cooking in 2008 in Malawi. Data from Table 2. (b) Sources and percentage of household using the fuel for lighting in 2008 in Malawi. Data from Table 2.

electricity is consumed relatively high is the service sector (29%) followed by industry (10%). Petroleum consumption is dominant in the transport sector (94%), followed by the service sector (34%) and Industry (16%). Coal is consumed in the industry sector (18%) and service sector (11%).

Most of the household energy demand is for thermal applications, especially for cooking and lighting services. It is seen from Fig. 3 that fuelwood (firewood) is the dominant cooking energy in Malawi; 88% of the households use fuelwood for cooking. In rural and urban areas, firewood provides cooking energy to 96% and 42% of households respectively. Charcoal provides cooking energy to 43% and 2% of urban and rural households. Electricity provides cooking energy to only 2% of the entire households and 38% of the urban household. Therefore, fuelwood is the dominant cooking fuel for both rural and urban households while charcoal is mostly used in urban areas. Urban households spend more income on charcoal than on electricity; about three-quarters energy costs are spent on charcoal [28].

The technologies for consuming fuelwood are inefficient. Most of the firewood is consumed using the traditional inefficient

Table 2
Sources and shares of household energy for cooking and lighting services in 2008 at national, rural and urban levels in Malawi [10].

Energy source	Cooking (% of population)			Lighting (% of population)		
	National	Rural	Urban	National	Rural	Urban
Charcoal	8	1.7	43.4	0	0	0
Electricity	2	0.4	13.6	7.2	1.9	37.5
Firewood	88	95.7	41.8	2.6	2.9	0.4
Gas	0	0	0.1	0	0	0
Paraffin	1	1.2	0.7	85.7	92.5	46.5
Candle	0	0	0	3.2	1.1	15.3
Others	1	1	0.4	1.3	1.6	0.3

'three-stone' open fire cooking stoves. Some interventions are underway to introduce households to relatively efficient firewood cooking stoves. Portable stoves made of metal with ceramic lining are used by those households that use charcoal for cooking and heating. Paraffin (kerosene) is the most dominant source of fuel for lighting among Malawians. About 86% of the entire households depend on paraffin for lighting: 93% in rural households and 47% in urban households (Table 2). Only 7% of the entire households use electricity for lighting, which signals that about 7% of the households had access to electricity in 2008 since lighting is the principal use of electricity in any home (Table 2).

From the general overview on energy consumption and supply characteristics in Malawi, it is seen that the country is a low energy consumer. Biomass, in the form of fuelwood and charcoal, is the most significant form of energy in the country. While the main use of fuelwood is for cooking and other forms of thermal energy services in the household sector, the industry sector also uses it for process generation of steam but on a smaller level. The fuelwood consumed by the household sector is collected from natural forests and illegally from protected forest reserves and plantation forests. Collecting and selling of fuelwood as well as charcoal is the source of livelihood for some Malawian households, as evidenced from stockpiles and heaps of bags of firewood and charcoal respectively, displayed for sale along major roads and market places. In fact, a study on charcoal trade conducted in four major urban areas (Blantyre, Zomba, Lilongwe and Mzuzu) by Kambewa and others in 2007 [28] revealed that the trade had an estimated value of US$ 41.3 million contributing to about 0.5% of the country's GDP.

Malawi is one of the countries in Africa that are faced with challenges of increased rates of urbanisation [29]. The increased rate of urbanisation has been known to contribute to increases in the demand for charcoal in urban areas. This has resulted into increased levels of harvesting of indigenous forests (even from the protected forest reserves) to produce charcoal contributing towards deforestation [28,30]. Fuelwood demand is in excess of sustainable supply for large parts of Central and Southern Regions [25]. It is reported that some charcoal that is sold to Blantyre city and other urban areas in the southern region come from Mozambique [28]. Although charcoal production, transport and selling present income generating opportunities for the majority of low income earners in the country, if produced unsustainably, charcoal trade can affect performance of other economic sectors like undermining production of ecosystem services (e.g tourism), limiting agricultural production and affecting human health.

As a biomass energy consuming economy, managing the forest resources for sustainable livelihood in the energy sector is one of the opportunities in the energy sector in Malawi. Therefore, diversification from fuelwood and charcoal to other locally available and affordable alternative sources is also an area that needs to be exploited in the energy sector. Apart from diversification of

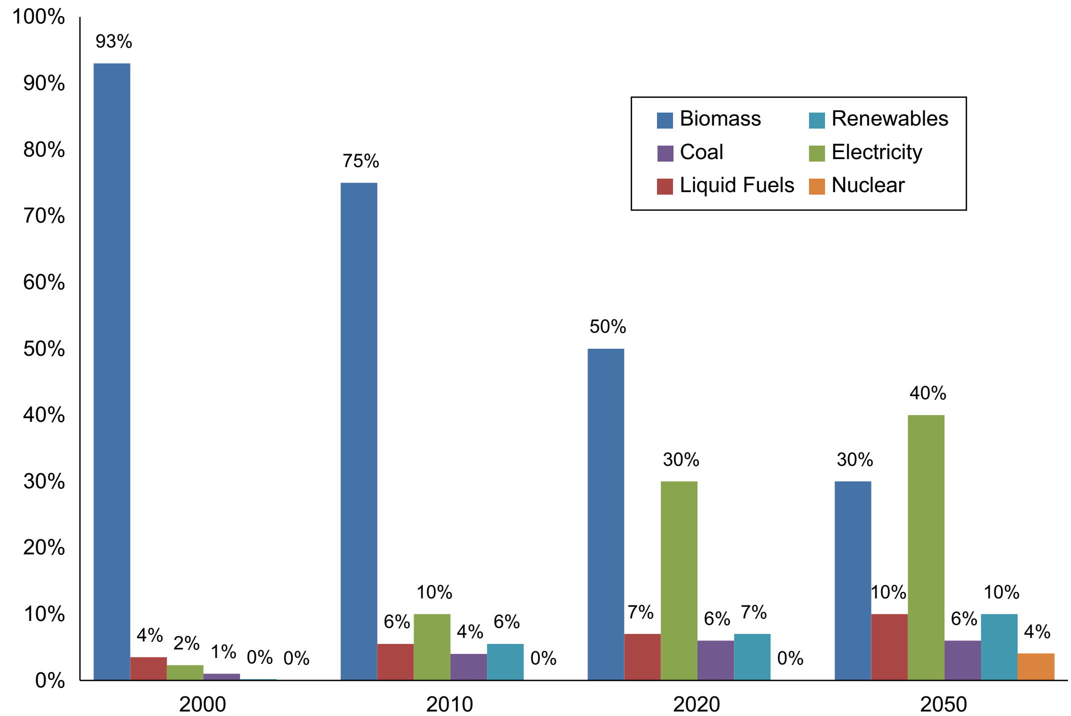


Fig. 4. The proposed Malawi energy mix projections upto the year 2050. The vertical axis is the percentage share of energy source with respect to the total primary energy supply for that year [31].

energy sources, promotion of efficient energy end-use technologies should be encouraged and opportunities in this area should be exploited. Much of the focus should be directed towards the household sector especially concerning thermal energy consumption (cooking and heating) considering its significant in biomass energy consumption in the country. Renewable energy technologies that provide for thermal services such as briquettes, biogas, ethanol cooking stoves, ethanol lamps and solar thermal should be promoted in the Malawian household sector because of the availability of the energy resources. Cooking using modern forms of energy such as liquid fuel (paraffin), electricity and gas is considered by some to be expensive when compared to charcoal; however survey conducted by Kambewa and others [28] showed the opposite (concerning electricity). Therefore awareness campaigns on other sources of energy for energy for cooking and heating should be encouraged. Electricity provision especially in the household sector can greatly offset paraffin as a major lighting energy source but very unlikely as a cooking energy by the same level of significance. Lighting load is generally low and therefore it is important for decentralised renewable energy electricity generating systems like solar, wind and small-scale hydropower to be used for income generating activities in addition to providing lighting services.

4.2. Malawi energy reform programmes and projects

Policy and technological interventions are required in order to modernise and improve the operations of the energy sector so that it contributes to sustainable development of a country. In view of this, Malawi, in 2003 developed the National Power Sector Reform Strategy that provided the background for the formulation of the liberalised Malawi Energy Policy. The energy policy allows private sector to invest in the energy sector, whether in energy generation, transmission, supply and service undertakings. The policy states that private sector can operate solely or in partnership with the government. The main objective of the energy policy is to progressively decrease the percentage share of biomass by increasing the share of non-biomass energies in the national energy mix, such that by the year 2050, 30% of the total primary energy supply should be sourced from biomass, as seen in Fig. 4. The active participation of the private sector is important for the achievement of the policy objective.

The development of the energy policy paved the way for the formulation of energy laws and regulations in 2004 and 2008 respectively to create a legal and regulatory framework suitable for the participation of private sector in the energy sector [32,33]. The following are the energy laws: (i) The Energy Regulation Act 2004; (ii) The Electricity Act 2004; (iii) The Rural Electrification Act 2004; and (iv) The Liquid Fuels and Gas (Production and Supply) Act 2004. Three out of four energy regulations were gazetted in 2009. These are: (i) The Energy Regulation By-Laws, 2008; (ii) The Rural Electrification Regulations, 2008; (iii) The Liquid Fuels and Gas (Production and Supply) Regulations, 2008; and (v) The Electricity By-Laws were established in 2012. The Malawi Energy Regulatory Authority (MERA) was established under the Energy Regulatory Act of 2004 as a corporate body responsible for the sector wide energy regulation. Among others, MERA has the following mandates: (i) receiving and processing licence application for energy undertakings; (ii) approving tariff and prices for commercial energy sales and services; (iii) promoting energy efficiency and savings; (iv) facilitating increasing access to modern energy supplies and (v) promoting the exploitation of renewable energy sources. The challenge may be to implement the policy provisions within the legal framework as well as to enforce the regulations in an impartial and professional manner suitable for the development of a liberalised energy sector considering the fact that the Malawian liberalised energy sector is still in its infancy stage.

Formulation of the energy policy also informed the government to develop rational and implementable plans to manage the biomass energy sub-sector in the country. In this regard, in 2009, the government came up with the Malawi Biomass Energy Strategy (BEST). The BEST has designed measures to improve the sustainability of biomass energy supply, raise end-user efficiencies and promote traditional biomass alternatives [25]. The strategy

has implementation plans both at national and district levels. The challenge to implementation of the strategy might be the limited human and financial resources.

At national level, there have been programmes on reducing traditional biomass energy consumption as well as promotion of modern forms of energy. Most of these programmes are jointly implemented by the Department of Energy Affairs (DoEA) and development partners. For example, the four-year Promotion of Alternative Energy Sources Project (PAESP) which was launched in 2006 had the objective of reducing environmental degradation that results from unsustainable harvesting of forest for fuelwood and charcoal through promotion of alternative sources of fuel and their technologies for cooking and other thermal applications in the household sector. The main alternative technologies that were promoted were briquettes, ethanol stoves and biogas.

The DoEA is also embarking on the Malawi Rural Electrification Project (MAREP) which is implemented jointly with the Government of Japan through Japan International Cooperation Agency (JICA). The main objective of MAREP is to provide modern power for economic activities in rural growth centres (also known as Trading Centres) and for possible household and institutional applications. It can be hoped that through fuel switching for cooking and other thermal services, the fuelwood consumption will be reduced in the electrified rural growth centres. However, it is argued that the basic household's decision to switch to an alternative source of energy is dictated by the energy cost and the costs associated with purchase and maintenance of the energy end-use devices. The typical household's decision on alternate energies may likely not be influenced by environmental reasons. Most of the rural households, even those in rural trading centres have low disposable incomes for them to afford modern sources of energy like electricity. Against a background where fuelwood is collected for free or is available in rural markets at relatively cheaper price, the likelihood of rural households using the supplied electricity for cooking and other thermal services is low.

The other biomass energy project in the country is the Programme for Basic Energy and Conservation in Southern Africa (formally known as ProBEC), which is partly financed by the German Government through GTZ. Working in conjunction with the DoEA, ProBEC is involved in promotion of efficient firewood cooking stoves for household and institution applications in most of the districts in the country to replace the traditional inefficient three-stone open fire cooking stoves [34]. ProBEC has also been involved in promotion of efficient technology for curing tobacco in flue-curing barns using venturi-based chimneys that enhance combustion.

The country has had national programmes to promote renewable as one of the significant sources of modern energy supply. For this purpose, in 1999, the National Sustainable and Renewable Energy Programme (NSREP) was launched to embrace all renewable energy projects implemented by the government and other development partners like United Nations Development Programme (UNDP), Danish International Development Agency (DANIDA) and the Global Environmental Facility (GEF). The main renewable energy technologies that were focused were solar PV, solar thermal, wind turbines, biogas and biomass briquettes. One of the outputs of the NSREP was the identification of barriers to implementation of renewable energy in the country. As a result, a UNDP implemented national project, the Barrier Removal to Renewable Energy in Malawi (BARREM), was launched in 2002 and got terminated in 2008. In terms of demonstration of renewable energy technologies in the country, the BARREM project concentrated on promotion of solar PV only [35]. The BARREM Project resulted in the emergence of several renewable energy companies which are organised under the umbrella organisation known as Renewable Energy Industry Association of Malawi (REIAMA). Despite having some challenges, emergence of renewable energy industries was an indicator of increasing awareness of renewable energy in Malawi. The Mzuzu University, which was one of the participating institutions in the BARREM Project, is carrying out some of the activities of BARREM in the area of training and testing of renewable energy technologies. A centre for Testing and Training of Renewable Energy Technologies (TCRET) is instituted at Mzuzu University. TCRET was designed to work in collaboration with the Malawi Bureau of Standards and Department of Energy Affairs to ensure standard installation of renewable energy technologies and their system maintenance in the country. Apart from offering short term trainings, Mzuzu University also offers a B.Sc. in Renewable Energy Technologies.

The Government of Malawi also supported the installation of six stand alone solar PV-wind hybrid electricity generating systems (locally known as solar villages) for demonstration throughout the country. Despite the awareness of renewable energy (especially solar PV) in the country, the installation of solar PV systems has been mainly focused on institutions especially the rural health centres, secondary schools and police units: typical applications being lighting, cooling (using refrigerators) and water pumping. Use of solar PV for income generating activities in the rural growth centres (supporting small scale industries) has not been successful because of limitation of solar PV power system to provide for thermal and mechanical energy services. Maintenance of the solar PV systems has been the main challenge in Malawi's institutional installations and there has been a general feeling that solar electricity is inferior and difficult of manage. Therefore, there is also need to diversify renewable energy generation sources. Small-scale hydropower has been proven elsewhere to provide enough electricity and mechanical power to support small scale industries in an off-grid community.

4.3. *Electricity sub-sector*

As the case with most of the sub-Saharan African countries, the electricity sub-sector in Malawi is small, both in absolute and relative terms. The total installed capacity is about 350 MW, almost all of which is sourced from run-of-river hydropower stations located in the Shire River in a cascade arrangement. Only 4.5 MW small-scale hydropower station is located up north of the country at Wovwe in Karonga District. Considering the geographical orientation of the country, electricity is transmitted through a relatively long distance to reach the northern parts of the country which obviously creates challenges in transmission and distribution. At the hydropower stations, electricity generation is affected by poor water quality due to siltation and aquatic weeds which are consequences of the degradation of the environment in the catchment area [36]. The other challenge in the electricity sector is frequent requirements for maintenance of the power infrastructure of which some parts were installed relatively long time ago; for example the current 24 MW Nkula A hydropower plant was installed in 1966 [37]. Management of peak power demand is also a challenge. The result to these challenges is the unreliability of electricity supply.

The unreliability is characterised by frequency of unplanned power outages. The 2007 World Bank Survey revealed that Malawi had on average 63 days in a year without electricity as a result of unplanned power outages [3]. The power sector assessment study conducted by the Millennium Challenge Account (Malawi's Energy Sector Project) also noted the Malawi's relatively high level of electricity unreliability cost the country around 2–3% of the GDP in 2010 [38]. This means the country could earn more by making improvements in the electricity sector. There is a need to revamp the energy sector to recover most of the unavailable capacity back into the grid and reduce system losses, as well as manage the siltation and weed infestation challenges. Some of these initiatives

are being executed currently by ESCOM with financial support from the Government of Malawi and a US$350 million grant from the government of United States of America through The Millennium Challenge Corporation [39].

The Electricity Supply Corporation of Malawi (ESCOM) power expansion programme has largely remained stagnant over some years in the past and the government is looking for the private sector to partner with in the power expansion programme through public–private partnerships [38]. Since 2010, the available installed capacity has been 282.5 MW. Most of the times, especially during the rainy season, the available installed capacity becomes lower than 282.5 MW because of machine shut-down due to problems arising from siltation and aquatic weed infestation [37]. Currently, there is an ongoing installation of an additional hydropower station of 64.8 MW at Kapichira Falls (Kapichira II Project) in the Shire River and is expected to be commissioned in December 2013. The Government of Malawi and the Government of Mozambique have in early 2013 signed an agreement that allows both countries to trade power to each other.

Grid-based electricity generation, transmission, distribution and customer service is the sole responsibility of ESCOM, a state owned company. The current national electricity demand is above 350 MW; not considering the electricity requirements from the mining sector, which are estimated at more than 1000 MW [40]. This is clearly a suppressed demand. ESCOMs Electricity demand projections (not including mining requirements) in 2015, and 2020 are 478 MW and 757 MW respectively [38]. ESCOM is unable to connect all domestic applications and potential mining loads due to inadequate capacity and security to supply reliable electricity. For instance, Paladin Africa Limited generates own power at Kayelekera Uranium Mining Project site (about 10 MW), since ESCOM could not guarantee secure, reliable and adequate power supply [40]. Private sector participation in the generation of electricity in Malawi is almost nil, except for a few thermal electric power plants using coal, diesel and bagasse that have been installed for private use in industries and some rich households. The Malawi Energy Regulatory Authority in 2010 estimated that about 63 MW is generated from gen-sets as decentralised power systems for private use in the country (including the Kayelekera diesel electric generator). The electricity sub-sector in Malawi is highly susceptible to environmental degradation in Shire River catchment area and climate change negative impacts. It is recommended to diversify power expansion projects to other important rivers or other sources of power generation such as fossil-fuel thermal power plants and renewable energy.

With the foregoing brief description on the electricity sub-sector, it is not surprising to note that Malawi is one of the least electrified countries. The quoted data on current (2012) information on national access to electricity varies between 8% and 10% [21]. The MGDS II states that 9% of the population have access to electricity. In rural areas, less than 1% of the households have access to electricity [21]. The country's annual electricity consumption per capita is 111 kWh per capita [38]; which is low even at regional level. The annual electricity consumption per capita for Southern African Development Community (SADC), according to a report by the Infrastructure Consortium for Africa, is 1767 kWh per capita [41]. A population of nearly 15 million and an installed capacity of 350 MW gives an installed capacity of 23 MW per million inhabitants. This indicator is again very small compared to the average installed capacity for the whole of the sub-Saharan Africa region which is 110 MW per million inhabitants [42]. However, the average installed capacity for sub-Saharan Africa region is weighted strongly by South African's installed capacity of 40 GW (as of 2008); therefore, minus South Africa, the rest of the region's (composed of 48 countries) total installed capacity drops to only 28 GW [3] which is slightly less than the installed capacity for Norway alone (31 GW in 2009) [43].

4.4. Modern energy resources

Despite the shortage in commercial energy supply, study reports and data from the industry show that Malawi has considerable amount of energy resources, which if exploited, may supply all of the country's energy requirements including electricity. The study by the Millennium Challenge Corporation in Malawi, estimates that the country has a hydropower generation potential of over 1,000 MW [44] of which only about 350 MW has been installed, as stated earlier. Girdis and Hoskote working for the Energy Sector Management Assistant Program (ESMAP), state that Malawi has four coalfields-three in the north and one in the south parts of the country with an estimated reserve of about 80 million tonne with proven reserves amounting to approximately 20 million tonne with energy values ranging from 17 MJ/kg to 30 MJ/kg [45]. Currently, coal is mined at Kaziwiziwi and Mchenga in Rumphi District with an annual production average of 25,000 t/year and 36,000 t/year respectively. Ethanol is produced at Dwangwa in Nkhotakota and Chikwawa districts from molasses by the Ethanol Company and Presscane Limited at a total production rate of 50,000 l/day [46]. Currently, most of this ethanol is blended with petrol at a ratio of 10:90. Studies by the Lilongwe Technical College research group with support from the Malawi National Research Council show that it is possible to achieve a blend ratio of 20:80 without affecting the performance of the petrol engine [47]. The Malawi Energy Regulatory Authority has so far mandated liquid fuel providers in the country to blend petrol with ethanol at this ratio [40]. There is also potential from cogeneration thermal power plants at Illovo sugar factories at Nchalo in Chikwawa and Dwangwa in Nkhotakota using bagasse; which could to sell excess power to the grid.

Malawi is also well endowed with renewable energy resources such as wind, solar and biogas. Solar irradiation potential is estimated at 21.1 MJ/m^2/day which is adequate for photovoltaic and solar-thermal applications, wind speeds averaging 2–7 m/s for electricity generation and provision of mechanical work and biogas from animal husbandry, municipal and agro-wastes. There are also occurrences of hot springs in Nkhotakota which could be studied to determine if they are feasible for geothermal power generation [18]. Some documents and experts verbal communication indicate that Malawi has some potential for generating small-scale hydropower (SHP). As stated earlier, apart from discussing energy situation, it is also the purpose of this paper to document and discuss information concerning SHP potential, utilisation levels, challenges and opportunities in the country. Before this is presented, the following section of the paper briefly describes the SHP technology in order to inform the reader who may not have the basics necessary to appreciate the discussion that follow on Malawi's small-scale hydropower.

5. Small-scale hydropower technology basics

Small-scale hydropower (SHP) plants are energy systems that generate electricity and/or mechanical energy (usually of smaller capacity) from hydraulic energy in the flowing water. These hydropower plants (or systems) can be categorised in terms of their level of 'smallness' of installed capacity as indicated on the nameplate of the generator. The upper limit of 'smallness' is not universally agreed upon but it seems 10 MW is widely stated as the upper limit; for example in most of the European countries and some organisations such as the World Commission on Dams [48]. Within the SHP category, these power systems are further categorised into small hydropower, mini-hydropower, micro-hydropower and pico-hydropower systems. Again, the categorisation within the SHP is not uniform across countries, organisations

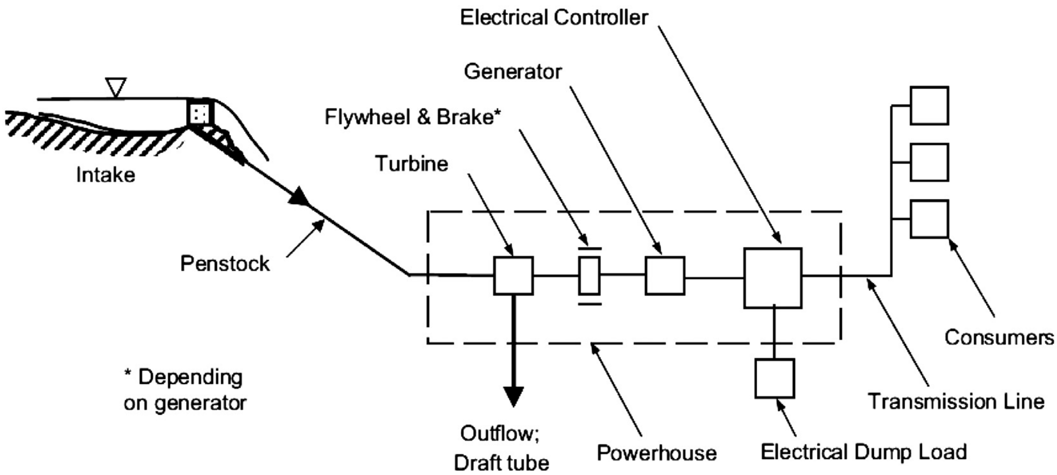


Fig. 5. Arrangements and elements of a typical SHP system [52].

or amongst individual experts. For example, according to Paish [49]; mini-hydropower, micro-hydropower and pico-hydropower refer to systems generating less than 2 MW, 500 kW and 10 kW respectively. Practical action puts a limit of 15 MW for a small hydropower system; above 100 kW, but below 1 MW it is mini-hydropower; from 5 kW up to 100 kW it is micro-hydropower and from a few hundred watts up to 5 kW it is a pico-hydropower system [50]. A level of 100 kW appears in most literature as the upper limit of micro-hydropower systems.

Categorisation of hydropower in terms of installed capacity finds application in legal documents. For example, in the Malawi Rural Electrification Act, micro-hydropower refers to a hydropower system whose installed capacity is more than 2 kW but is less than 100 kW; mini-hydropower station is a hydropower station whose installed capacity is not less than 100 kW but is less than 500 kW [51]. It should be mentioned that sometimes the SHP system is loosely synonymous with micro-hydropower system. Micro-hydropower systems are typically used as an off-grid electricity supply to a community. For a typical rural trading centre in Malawi, 100 kW of electricity supply is enough for institutional, household and small scale industry applications. Because micro-hydropower system is considered to be too small, they are not considered for development by most of the power utility companies. This can be the opportunity for private sector involvement as independent power producers in the country.

Classification of SHP system according to head (e.g high head, medium head and low head plant) is also used in practice. Some systems are also named after their types of the turbines (e.g Francis Turbine microhydropower plant).

Most small-scale hydro-systems, especially micro- and pico-hydropower systems are run-of-river types. In run-of-river types, a stream is just diverted from the main river to the powerhouse to generate power. Water is usually barraged using a weir at the point in the river where the stream is diverted. There is generally no significant water storage. As such, these energy systems are not associated with adverse impacts on the local environment as the case with large scale hydropower systems with dams. Some SHP systems with a larger generating capacity (small and mini-hydropower systems) may incorporate small dams; or the hydropower system may be retrofitted to existing dam. Because of being an environmentally friendly technology and flowing water in perennial rivers being a renewable energy resource, SHP systems are some of the important clean energy systems considered for carbon trading such as the Clean Development Mechanism.

The basic arrangement and elements of the SHP system is the same for all systems and is relatively simple. Fig. 5 shows a schematic diagram of the typical arrangement of the system. The elements of a typical SHP system are usually divided into hydraulic, electro-mechanical and load components. Hydraulic components convey water from the river intake via the weir, channel, settling tank and penstock to the powerhouse. Valves to control flow direction and flow amount as well as to dissipate excess energy are also part of the hydraulic components. Electro-mechanical components include energy conversion devices such turbines and generators. Mechanical power transmission system (e.g gears, belts, and shafts), control system and electrical power transmission systems are also part of the electro-mechanical components. Turbine, generators, mechanical transmission system and control system are placed in the powerhouse. Fig. 5 shows some of these components.

In general, hydroelectric power system is an efficient energy system. Even though due to size effects, the performance levels of SHP systems are less compared to large scale hydropower systems, SHP systems are more efficient than fossil fuel electric generator and other renewable energy electricity generation technology such as wind and solar. Some basic components of the SHP technology are discussed in the following sub-sections:

5.1. Water turbine

Water turbine is the 'heart' of any hydropower system. It is basically a hydraulic machine that converts the hydraulic energy in the flowing water into mechanical energy in the form of shaft power. The hydraulic energy or just the hydropower potential at a particular site is given by Eq. 1:

$$\text{Hydraulic energy} = \rho g H Q \tag{1}$$

where ρ (kg/m^3), is the density of water g (m/s^2) is the acceleration due to gravity (m/s^2), Q (m^3/s) is the water flow and H (m) is the available head across the turbine which is given as the difference in water levels between intake water and turbine tailrace water.

Not all of the available hydropower potential is converted into shaftpower because of inevitable losses in the hydraulic conveyance system and in the turbine. The shaftpower can be used to power devices or generate electricity or both at the same time (especially for micro- and pico-hydropower systems). The shaft power is given by Eq. (2):

$$\text{Shaft power} = \eta_c \eta_m \eta_t \rho g Q H \tag{2}$$

where η_c is the hydraulic efficiency in the conveyance system (penstock and valves); η_t and η_m are the hydraulic and mechanical efficiencies of the turbine respectively. The hydraulic efficiency in the turbine depends on several factors including: (i) friction between flowing water and various surfaces of the turbine; (ii) incidence

losses on turbine runner blades and other parts of the housing as water flows through the turbine transferring energy in the process and (iii) energy loss when water flow in the turbine changes profile due to deviation from best efficiency design point resulting in whirl and separation losses. In general, the hydraulic efficiency depends on the type of the turbine system and operating conditions (speed and flow rate). Mechanical efficiency depends on the bearing losses of the turbine shaft.

The shaftpower can be measured because it is also given as the product of the torque generated by the turbine and its angular speed.

For a particular installed system, Eq. (2) is also written as

$$\text{Shaft power} = KQH \tag{3}$$

where K is a constant and is equal to the product of the efficiencies, water density and acceleration due to gravity. It is a constant because the values of these products are fixed for any particular site for the given turbine. From Eq. (3), it can be seen that the shaftpower that the system can extract from a site is a function of flow and head only. Apart from quantifying the energy resource potential at a particular site, flow and head are also used to select the required type of turbine for the particular hydropower site.

There are many types of turbines used in the SHP technology. Basically, they are grouped according to their principles of operation in which case they can either be reaction or impulse turbines. Examples of reaction turbines include Francis, Kaplan and Propeller turbines while Pelton, Turgo and Crossflow turbines are examples of impulse turbines.

Reaction turbines utilise both the pressure in the water and change of momentum of water flow to generate forces to drive the runner. In this case, the water pressure reduces across the runner as energy is transferred from the water to the runner. Therefore, the runner must operate in a water-tight housing at all times. The reaction turbines are therefore susceptible to cavitation and leakage losses. Most reaction turbines have a diffuser known as a draft tube below the runner through which the water discharges to the tailrace. The draft tube slows down the discharge water converting some residual kinetic energy into a positive suction head which increases the effective head across the runner. On the other hand, for the impulse turbine, the hydraulic energy in the water is converted into kinetic energy in form of water jets by the nozzles. The water jets impact the runner blade and due to change of momentum of the water, a force is created on the runner blades which makes the turbine rotate. The pressure across the runner of the impulse turbine is essentially constant at atmospheric from the inlet to the outlet. Generally, impulse turbines are used for high head sites while reaction turbines are used for low head sites. Charts obtained from studies on different types of hydropower turbines, such as the one given in Fig. 6 can be used in preliminary selection of the turbine for the site from the knowledge of effective head and flow rate.

Specific speed of the turbine is another criterion to be considered when selecting turbine type and can be calculated using Eq. (4) from the knowledge of working turbine speed (which can be obtained from synchronous speed of generator and gearing ratio or shaft speed of work consuming device), power required (basing on power demand) and head (from the site).

$$N_s = \frac{NP^{1/2}}{H^{4/5}} \tag{4}$$

where N (revolutions per minute) is the working speed of the turbine, P (kW) is the maximum turbine power output and H (m) is the net head.

The specific speed, together with other fundamental laws can be used to scale-up an existing design of known performance to a new size with corresponding performance. Selection of small scale

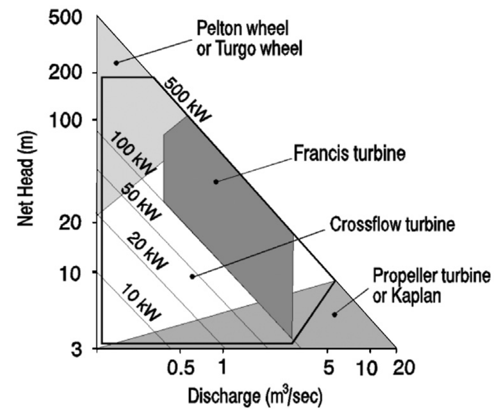


Fig. 6. Turbine selection chart basing on head and flow [49].

turbine for a particular site also depends on costs and level of technology preferred. For micro- and pico-hydropower systems, the emphasis is more on cost reduction than on technical performance and as a result the turbine design, manufacturing and installation processes for such SHP turbines are not as rigorous as in large scale hydropower turbines. However, this does not mean that the design, manufacturing and installation processes of small-scale turbines should be largely compromised because economic performance of the system also depends on its efficiency levels.

5.2. Generator

A generator is an electro-mechanical device that converts mechanical power (shaft power) into electrical power. The water turbine is usually coupled to a generator to produce electricity. The generator that produces alternating current is technically referred to as an alternator. The generator that produces direct current is referred to as a dynamo. The alternator is mostly applied in SHP systems.

Some electrical appliances are designed to be operated at a certain voltage and frequency. Thus, the generator should produce constant voltage with constant frequency to avoid damage to such electrical appliances when they operate outside the rated voltage and frequency. For a generator system, if the amount of load that is available at the generator is varied, the velocity of the generator (hence its frequency) will vary too which can affect the voltage produced. The change in velocity of the generator can also cause damage to the generator itself and the entire coupled rotating system due to accelerating/deceleration forces according to the Newton Second Law of motion. For SHP systems, if the generated electricity is fed into the national grid, then there is no problem of the variation of load across the generator because all electrical power generated is taken up by the grid (which is regarded as infinite load). However, most SHP systems are operated in standalone mode supplying power to varying load. Control systems and governors are therefore needed to protect the system against frequency fluctuations.

Governing can be achieved either by controlling amount of flow to the turbine or controlling load available on the generator. Control using flow is achieved by employing mechanical/hydraulic governors while electronic load controllers (ELCs) govern the frequency fluctuations by controlling the load on the generator. ELCs govern the turbine speed by maintaining a constant load (full load) on the generator despite variation of load from the consumer because the excess power is dissipated by a ballast load. In this case, the turbine guidevanes (or valves) are kept open at their maximum position in order to ensure a constant flow and hence

guarantee the availability of constant shaft power at the generator shaft. Energy dissipated by the ballast load during the load control process is usually wasted but it can be used for other productive uses for example in ice making and cooling. Mechanical/hydraulic governors are usually more expensive than ELCs and are more applicable to large scale hydropower systems than to small-scale ones. ELCs are mostly used in micro- and pico-hydropower systems and their advent is stated to have contributed to having reliable and cheap installed SHP systems [49].

5.3. Drive system

The drive system transmits power from the turbine output shaft to the generator shaft or to the shaft that powers the work consuming device. In micro- and pico-hydropower systems, the drive system also has the function of changing the rotational speed from one shaft to the other when the turbine speed is different to the required synchronous speed of the alternator or work consuming device. The drive system includes the following elements: shafts, gearbox, bearings, keys, belts, chains, sprockets and pulleys. The Drive system not only reduces the system efficiency but also increases the investment cost. Correct design of the drive system is therefore necessary to reduce mechanical energy loss during power transmission. This calls for mechanical engineering component sizing and parts selection.

5.4. Small-scale hydropower economics

The initial investment of SHP system is site specific. The conditions of the site determine the costs associated with civil works. The civil work costs depend on the gradient of the site. Sites with steep slopes need shorter penstock lengths and generally have lower investment cost (due to reduced penstock costs) per kW of installed power than sites with gentle slopes. This shows that river sites in the mountainous locations present best potential sites for SHP systems; both on cost and maximum energy extraction.

The other investment costs are those associated with electro-mechanical generating equipment (turbine, generator, control and protection) and electrical transmission/distribution lines. The cost of electrical line (mini-grid) depends upon the electricity energy density of the load centres. The initial investment cost of small and medium scale hydropower is reported to be over 2000US$/kW of installed capacity [53,54]. This compares well with investment cost of wind and solar PV energy systems. The cost for wind power system is reported to typically range from €1000/kW to €1350/kW (1500US$/kW to 2000US$/kW) [55]. According to the International Energy Agency, typical investment cost of solar PV system ranges from 4000US$/kW to USD 6000US$/kW for small-scale applications [56]. Costs involving conducting feasibility study and system design should also be taken into account.

As discussed, the typical investment cost of the SHP system is still relatively high and the system installation looks attractive if the system has a high load factor and the power generated is used for supporting income generating activities. In some projects, cost-benefits analyses are conducted to determine how worth the project is.

Due to relatively high investment costs, most of the SHP projects in developing countries are initiated by the central governments and other development partners as part of the initiatives to bring electricity to unelectrified off-grid communities. The initial investment can be lowered by utilising locally manufactured components using local materials and labour (if required capacity is available). Relatively cheap manual labour during installation can be sourced from community members. This may be appropriate for pico- and micro-hydrosystems, but for mini- and small-hydropower systems, the project typically involves traditional engineering approaches and will for example, involve construction of access roads for delivery of materials, design and purchase (or manufacturing) of expensive electro-mechanical equipment and control system. Such activities

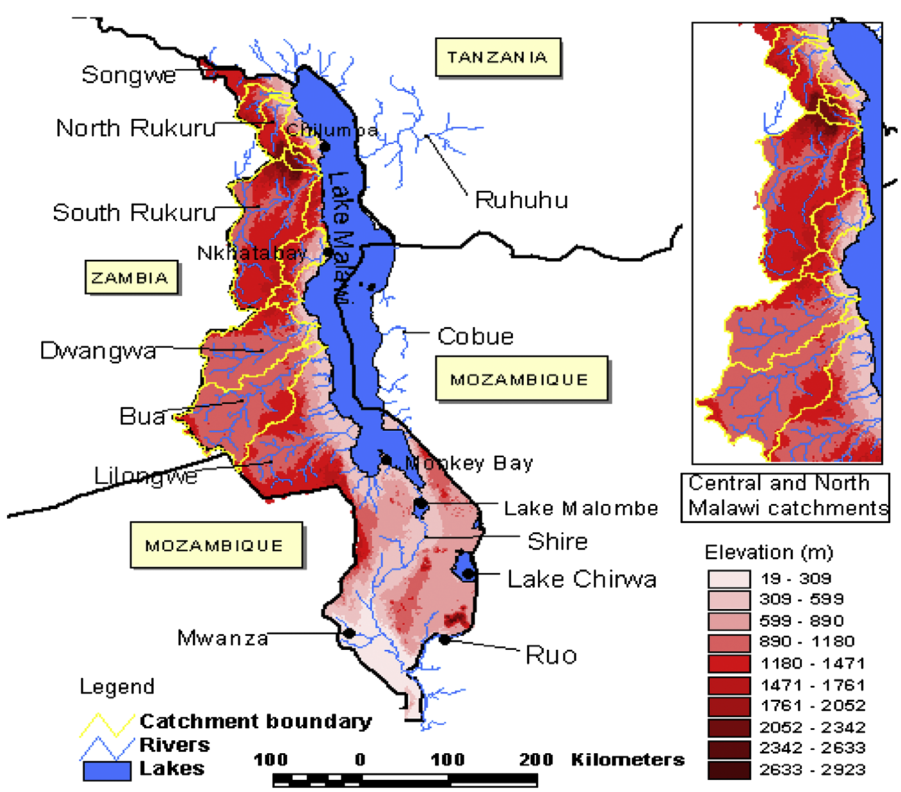


Fig. 7. Topography and river system of Malawi [58].

may not be localised due to lack of specialised labour and availability of materials.

6. Malawi's small-scale hydropower potential

This section presents the potential as well as status of small-scale hydropower (SHP) in Malawi. In this section, water resources, review of SHP previous assessment studies, status, challenges and opportunities are presented.

6.1. Malawi's water resources

Many studies and documents report that Malawi is relatively rich in water resources in form of lakes, rivers and aquifers some of which can be used for small-scale hydro-power generation [22,57]. Fig. 7 shows major rivers and general topography of Malawi. The trend of annual mean flows in most rivers in the country for the past years shows no change apart from random fluctuations mainly due to annual rainfall variations [18]. As can be seen from the map, northern region of Malawi has more highlands and perennial rivers than the rest of the country which give indication of the level of suitability for SHP installations.

Water resource distribution is highly variable both seasonally and geographically and nearly 90% of the runoff in major rivers occurs between December and June [59]. The major inventory of water resources (dams, rivers and lakes) in Malawi was conducted in 1986 with the financial support of UNDP and the National Water Resource Master Plan-NWRMP was prepared [60]. According to NWRMP, the country is divided into 17 water resource units. Flow characteristics and topography of important rivers namely; Shire, Bua, Dwangwa, North Rukuru, South Rukuru, Rumphi, Songwe, Wovwe, Lufira, Dwambazi, Luweya and Ruo give a picture of how well endowed Malawi is in hydropower resource potential. Hydrological and topographical information on these rivers can be sourced from the National Spatial Data Centre in the Ministry of Lands Housing Physical Planning and Surveys [58]. For SHP installations, technically it is possible to extract small streams from the main rivers for such purposes depending on the topography of the site.

In terms of dams, most of the structures were built in the 1950s when Malawi (Nyasaland) was under the federal government of Rhodesia and Nyasaland which administered by Britain. Most of these structures have been degraded to various levels such as reservoirs being silted up, spillways washed away and embankments breached. As can be seen from Table 3, the country had 749 small scale dams during the formulation of NWRMP.

In addition to the 749 small scale dams listed in Table 3, the Malawi Government and other development partners have also been constructing community-managed dams for water supply, fish farming and irrigation [60]. Therefore, the current number of small scale dams in Malawi should be more than 749. The large scale dams are relatively few and almost all of them are of earthfill type as shown in Table 4 [60].

The dams, both large scale and small scale were mainly built for water supply and few for irrigation. None was constructed for hydropower development. Retrofitting small-scale hydro-power systems to generate electricity on some of these dams can be possible, as evidenced by dam heights listed in Table 4. Further in water supply system from the dams, it is possible to replace energy dissipating valves with micro- or pico-hydropower systems. Thus, the dam inventory gives a good picture on the resource potential for small-scale hydro-systems in Malawi. For purposes of hydropower retrofitting and other generic functions of the available dams, it is necessary to rehabilitate dams that are degraded.

6.2. SHP potential assessment studies review

Despite having several perennial rivers, very few comprehensive feasibility studies have been conducted to identify some potential sites for SHP generation in Malawi. The technical information on identified and assessed potential sites for SHP generation is not available in consolidated form. So far, there have been three national resource assessment studies, which can as well be described as pre-feasibility studies since they used topographical and hydrology maps with some limited site surveys. The first study was conducted during the preparation of the NWRMP with the financial support of UNDP in 1986. In this study, 12 potential sites were identified, most of them in the northern region of Malawi, in particular in Karonga and Chitipa districts. These sites were then added to the National Energy Plan in 1987. In 1990, the German Consultants, Kennedy and Donkin, conducted a comprehensive feasibility study on only two of these identified sites, namely Wovwe and Lufila potential sites. The consultants recommended Wovwe project on both technical and economic reasons and a 4.5 MW plant was installed with the financial help from Germany. The installed Wovwe SHP is being operated by ESCOM since 1995. Currently, according to the Malawi Government concept paper for the energy sector, the study on the

Table 3
Inventory of small scale dams as in the National Water Resource Master Plan [60].

Number	Water resource area	Number of dams	Remarks
1	Shire	62	Most of them in Blantyre area
2	Lake Chirwa	31	Most of them in Thondwe and Namadzi area
3	South West Lakeshore	8	–
4	Linthipe	33	–
5	Bua	38	–
6	Dwangwa	50	–
7	South Rukuru/North Rumphi	274	–
8	North Rukuru	2	–
9	Songwe/Lufira	3	–
10	South East lake shore	1	–
11	Lake Chiuta	2	–
12	Likoma Island	0	–
13	Chizumulu Island	0	–
14	Ruo	215	–
15	Nkhotakoka Lakeshore	9	–
16	Nkhatabay Lakeshore	21	Almost all in Luweya and Limphasa area
17	Karonga Lakeshore	0	–
Total		749	

Table 4
Inventory of large scale dams as in the National Water Resource Master Plan [60].

Name	Location	Dam capacity	Catchment Area (km^2)	Dam height (m)	Type of dam	Use
Lunyangwa	Mzuzu City	4.36	25	19.5	Earthfill	Water supply
Chitete Dam	Kasungu Boma	4.5	44	12.2	Earthfill	Water supply
Mulunguzi dam	Zomba Plateau	3.375	18.9	45	Rockfill	Water supply
Mpira-Balaka	Ntcheu	3.72	42	29	Earthfill	Water supply
Kamuzu Dam 1	Malingunde in Lilongwe	5.2	–	18.4	Earthfill	Water supply
Kamuzu Dam 2	Malingunde in Lilongwe	19.0	1800	24	Earthfill	Water supply
Mudi dam	Blantyre City	1.4	8.903	17	Earthfill	Water supply
Lake Chingali	Nkhota-kota	–	14.35	–	Earthfill	Irrigation

Table 5
Malawi's small-scale hydropower potential sites and their characteristics as identified by the System Development and Operation Study Project [61].

Name of hydro-scheme	**Location (District)**	**Estimated parameters**					
		Net head (m)	**Mean flow (m^3/s)**	**Load factor (%)**	**Catchment area (km^2)**	**Firm power (kW)**	**Energy output (MWh/a)**
Kaseye	Chitipa	28	1.29	30	560	150	394
Kalenje1	Chitipa	122	1.08	30	80	230	604
Chambo	Chitipa	100	0.6	30	117	6	16
Mbalizi	Chitipa	187	0.98	30	270	30	79
Kalenje2	Chitipa	63	1.08	30	80	120	315
Upstream Lufira	Karonga	67	3.2	30	806	130	340
Lufira	Karonga	135	10.6	30	1380	940	2470
North Rukuru	Chitipa	132	11.9	30	1610	2250	5913
North Rukuru2	Karonga	75	11.0	30	1310	1070	2810
North Rukuru3	Karonga	83	6.35	30	698	670	1760
Wovwe	Karonga	194	3.01	30	140	1400	3680
Chisenga	Chitipa	15–20	0.1	30	4	15	39
Kakasu	Chitipa	10–30	0.1	30	8	15	39
Hewe	Rumphi	25–30	0.2	30	37	45	118
Ntchenachena	Rumphi	10–30	0.2	30	18	30	78
Murwezi	Nkhatabay	10–15	0.05	30	7	5	13
Zulunkhuni	Nkhataby	50–60	0.15	30	80	50	131
Sasasa	Nkhatabay (Usisya)	20–30	0.1	30	85	20	52
Ngapani	Mangochi	5–15	0.05	30	48	5	13
Mtemankhokwe	Mangochi	20–30	0.1	30	24	25	65
Nswadzi	Thyolo	5–15	1	30	380	75	197
Choyoti	Rumphi	30–40	0.2	30	13	60	157
Total estimated small-scale hydroelectric potential						**7345**	**19,283**

hydrology of Wovwe River indicates that the river site can generate up to 15 MW depending on the size and position of the weir [38]. The possible expansion of the Wovwe mini-hydropower site is one of the hydropower projects identified for possible public–private sector partnership initiative in the power sector.

In 1998, a second resource potential assessment study was conducted through a Power System Development and Operation Study Project with a funding from the World Bank to identify some SHP potential sites for connection to the national grid. About 100 hydropower potential sites were identified using topographical and hydrological maps obtained from the NWRMP. From this study, the Malawi Government eventually came up with a list of potential SHP sites, with a generation potential of about 7 MW as given in Table 5. These sites were then included in the ESCOM's Power Sources Development Master Plan (up to 2015).

The third SHP resource assessment was conducted in 2002 by the Japan International Cooperation Agency (JICA) technical team with some staff from the Malawi's Department of Energy Affairs, to identify sites that have potential to generate electricity between 5 and 200 kW to be included in the Malawi Rural Electrification Master Plan (MAREP). This study was more detailed than the first two since actual measurements were taken on the sites. Since the assessment study was for rural electrification, the candidates for potential sites were supposed to provide electricity to an existing non-electrified Trading Centre and that the Trading Centre was to be close to the potential site as well as have an accessible road to the site. The exercise, at desk study stage using maps and hydrological data analysis, identified 35 sites, 20 of them were in the northern region, 1 in the central region and 14 from the southern region. From the site surveys and interviews with villagers, a total of potential 11 sites with a power potential of 345 kW were selected from the 35 possible sites and have since been included in the MAREP. Most of the 35 identified sites were not considered as potential sites because they were either far away from the road or far away from nearest non-electrified Trading Centre despite having enough SHP potential. The characteristics of the identified potential sites for MAREP are given in Table 6.

There is a need to update the technical information on the two national SHP inventories because the hydropower potential may have been affected by environmental degradation in the catchment areas of the corresponding rivers as well as the prevailing impacts of climate change. There is also need to explore other SHP sites because the two inventories are not inclusive of all SHP sites in the country. This is so because some recent installed SHP projects have been developed on sites that are not included in the inventories. The following paragraphs discuss some private SHP assessment studies on some rivers.

The Malawi Industrial Research and Technology Development Centre (MIRTDC) conducted an energy baseline study for the Mulanje Mountain Conservation Trust (MMCT) and Practical Action in Mulanje and Phalombe districts (surrounding the Mulanje Mountain). The study revealed that the area is well

Table 6
Malawi's SHP potential sites according to Japan International Cooperation Agency Assessment Study as presented in the Malawi Rural Electrification Master Plan [62].

Potential site	District	River	Estimated capacity (kW)	Distance from the grid (km)
Chisenga	Chitipa	Chisenga	15	35
Mulembe	Chitipa	Kakasu	15	35
Nthalire	Chitipa	Choyoti	60	102
Katowo	Rumphi	Hewe	45	45
Nchenachena	Rumphi	Nchenachena	30	23
Khondowe	Nkhatabay	Murwezi	5	Difficult to assess
Ruarwe	Nkhatabay	Zulunkhuni	50	Difficult to assess
Usisya	Nkhatabay	Sasasa	20	50
Kwisimba	Mangochi	Ngapani	5	38
Katema	Mangochi	Mtamankhokwe	25	23
Sandama	Thyolo	Nswadzi	75	6
Total			**345kW**	

endowed with SHP potential of up to 104 GWh per annum [63]. Based on the findings from the MIRTDC energy baseline study, the Mulanje Renewable Energy Agency—MuREA, an NGO formed from the MMCT, with financial support from European Union and Practical Action, conducted feasibility studies on important rivers from Mulanje mountain namely; Luchenya, Lujeri and Ruo rivers. From these feasibility studies, MuREA has developed plans to install three community-based SHP systems in the area in three sites namely; 63 kW plant at Bondo, 98 kW plant at Manchebo and the 75 kW at Likulezi [64]. The development of the Bondo Village micro-hydropower project commenced with support from European Union and Practical Action. Currently (2013 April), the commissioning of the Bondo Village micro-hydropower system has been delayed due to some technical problems on the system.

In 2009, an organisation known as Greening the Tea Industry in East Africa (GTIEA) conducted a feasibility study on two sites on the upper Ruo River and one site at on the Lujeri River to develop and improve the capacity of an existing SHP system at the Lujeri Tea Estate in Mulanje District. The study, carried out by the Central Engineering Consultancy Bureau of Sri Lanka, concluded that development of hydropower at the sites was technically and financially viable, sustainable and environmentally acceptable and therefore, recommended the project to be implemented. The expansion of the existing SHP project was designed to generate excess electricity for rural electrification in the surrounding communities. However, the Lujeri Factory Management did not approve the project outright, but in phases, because the development of the site would mean taking out power for 18 months [64] that would affect the Factory operations. The existing micro-hydropower plant is the only reliable source of power for the Factory.

MIRTDC also conducted a feasibility study on the Chikangawa River in Kavuzi area in Nkhatabay District in the northern region of Malawi, for development of the SHP project. This project was initiated by a youth nongovernmental organisation of Kavuzi known as Media and Technology Society (MTESO). The study concluded that the site had a flow rate of 0.12 m^3/s, head of 26 m and that a 10 kW pico-hydropower system could be developed at the site. However, from these given parameters, a SHP system of more than 20 kW could be installed considering an overall efficiency of 70%. The SHP intervention in Kavuzi was initiated by the youth organisation that had constructed a simple hydropower system that was able to generate about 300 W power which was used for battery charging. Because of this initiative by the youth organisation, the Malawi Government through the Department of Energy Affairs and the Malawi Environment and Endowment Trust (MEET) wanted to expand the hydropower system to be used as a community demonstration project and hence they funded the feasibility study.

To conclude on this section, according to the available data on assessed sites as presented in this section, the proven potential for SHP in Malawi is estimated to be over 7.6 MW excluding potential through retrofitting hydropower systems on dams and other hydraulic systems in water supply and irrigation systems. However, most potential sites are yet to be assessed.

6.3. Status and application of SHP in Malawi

Available literature documenting characteristics of small scale systems installed in Malawi is quite sketchy with some of the technical data is missing. The earliest systems were installed by European missionaries and tea planters many years ago. According to reports and site visits conducted for this study, inventory and status of SHP systems installed in Malawi are given in Table 7.

Thus, from the inventory of the actual installed SHP systems in Malawi, it is estimated that the installed capacity is 5791 kW of which 5433 kW (including the 4.5 MW Wovwe plant) is currently available and 358 kW is not available. As can be seen from the inventory, none of the installed systems has been privately installed. It is also only Wovwe SHP system that has been developed basing on the national SHP assessment study.

6.4. Development and application challenges to SHP in Malawi

A relatively small installed capacity versus large SHP potential indicates availability of challenges. The challenges towards wide scale development and application of SHP systems in Malawi include the following:

- Limited local capacity to design and manufacture SHP systems components. In general, Malawi has shortage of human resource to undertake feasibility studies and detailed hydropower system engineering design that would include costing of the schemes so as to make a meaningful developmental impact on utilisation of potential SHP sites.
- Limited awareness of the SHP technology. Currently, only two NGOs; MTESO and MuREA, are involved in the promotion of the technology. There is need for further installation of demonstration units throughout the country to increase awareness levels.
- Relatively longer distances from the SHP potential sites to settlement points/load centres in most areas where most of potential sites are found, especially in the northern region of Malawi. This would increase investment cost of the SHP system per unit installed capacity due to increased transmission cost.
- Low levels of disposable income for users to pay for the electricity and their services in many rural areas of Malawi where most of SHP potential sites are found. This would discourage energy service companies to invest in the area and thus, promotion of the technology would rely on Government and NGOs to install the SHP systems as part of the campaign to provide electricity to rural communities.
- Apart from Tea and Coffee estates, there are limited business units in areas close to potential sites which could use the electricity for generating income. It is argued that the economic success of the SHP system depends largely on achieving a high load factor which could be obtained by using the scheme for income-generating activities in most of the times. It is further argued that presence of electricity can help to open up business opportunities in the un-electrified communities which can induce further demand for electricity.
- Electricity supply by ESCOM is subsidised. Unless the government also subsidises the electricity generated from private

Table 7
Inventory of installed SHP systems in Malawi and their status.

Name of installed system	Location	Status	Remarks
Matandani Micro-Hydropower	Neno District (previously, Neno was part of Mwanza District)	28 kW installed capacity. Installed in 1950s. Not functioning. Had been in operational state for more than 30 years.	Installed by the Seventh Day Adventist missionaries in Mwanza District. A study in 2000 revealed that it possible to rehabilitate and expand the micro-hydropower system to the nearby Neno Trading Centre (now Neno District Headquarters) [18]. Neno is currently served by ESCOM grid.
Livingstonia Microhydropower system (two units)	Rumphi District	20 kW installed capacity (estimated). Functioning. One generates electricity and the other operates a grinding mill	Installed by Missionaries of Church of Central African Presbyterian Mission many years ago.
Malosa Mini-hydropower System (two units)	Zomba District	300 total installed capacity. Installed in 1953 and 1954. Not functioning. Had been in operational state for more than 35 years.	Installed by the Federal Government of Rhodesia and Nyasaland (Malawi was Nyasaland then) to supply power to Zomba Town. Currently it is owned by ESCOM. Lack of maintenance and spare parts is stated to be the main reason for non functional. The pond constructed for power generation is now used for water supply [57].
Wovwe Small Hydropower	Karonga District	4.5 MW installed capacity. Functioning since 1995 when it was commissioned.	It is operated by ESCOM. The electricity generated is fed into the national grid and serves a considerable proportion of Northern Region power demand
Lujeri Estate Mini-Hydropower System (two units)	Thyolo District	840 kW installed capacity. Installed in 1934 and 1959 [63,57]. Functioning.	The electricity generated is used for powering machines in the Factory as well as supplying power for offices and staff houses.
Kongwe Micro-Hydropower	Dowa District	30 kW (estimated) installed capacity. Not functioning.	Installed by the Church of Central African Presbyterian Mission some years ago.
Kavuzi Pico-Hydropower	Nkhatabay District	10 kW installed capacity. Installed by MIRTDC with support from MEET and Department of Energy Affairs. Functioning.	The project supplies electricity to surrounding community members and the MTESO youth centre.
Bondo Village Micro-hydropower	Mulanje District	63 kW installed capacity. It is waiting for commissioning (April, 2013).	The system has been installed by MuREA with financial assistance from European Union and Practical Action [65]. The site was developed by expatriate and local staff. The project will provide electricity to the surrounding communities.

producers, the private sector participation in energy sector might be hindered. Private sector participation through Feed-in Tariff is one of viable interventions to promote decentralised energy technologies like SHP.
- Despite presence of a liberalised energy policy and the accompanying energy laws, there is no stand-alone renewable energy policy or strategy in the country to guide development and popularisation of SHP as the case with other countries such as Nepal and India.

6.5. *Opportunities for development of SHP in Malawi*

Despite the challenges, there are opportunities available for development of SHP systems in Malawi. These opportunities include the following:

- There is an acute shortage of electricity supply in Malawi in general and worst in rural areas where SHP systems are recommended as favourite forms of electricity supply. The northern part of the country where rural electrification is relatively worse than other parts is the part that has most potential sites for SHP.
- Presence of infrastructure for manufacturing basic SHP components. Most of the technical institutions in Malawi have sufficient facilities to manufacture the basic turbines or parts thereof. These include the University of Malawi—The Polytechnic Workshops, the Malawi Industrial Research and Technology Development technology production unit and Technical College workshops in various parts of the country. ESCOM also has workshops capable of producing some SHP components like turbines and generators. Private engineering workshops can also be in a position to manufacture such system components. However, local capacity is one of challenges in this regard, as already explained.
- Presence of the liberalised energy policy and the accompanying legal and regulatory frameworks in the energy sector which have created conducive environment for the participation of private sector in the power supply business
- The Government of Malawi promotes development of clean and renewable energy technologies. In this regard, the government has waived import duties on all renewable energy components and systems imported from outside Malawi by registered Renewable Energy Companies.
- The Government of Malawi has put micro-hydropower projects in its rural electrification master plan. This is another potential area for public–private partnerships in the power sector considering the fact that a lot of identified SHP potential sites are not yet developed.
- There is availability of potential users/load centres considering that the population and rural economy of Malawi is growing in some areas. Malawi grows a lot of tea and coffee in mountainous regions which have perennial streams. Therefore, there is opportunity for development of SHP in tea and coffee industries considering the fact that the grid based electricity supply is unreliable. Further, the excess generated electricity can be sold to the surrounding communities or to the grid.

7. Conclusions and recommendations

Malawi has economic and environmental challenges that make her stuck in the category of low income countries. This paper has shown that these challenges are partly due to the current relatively poor energy situation in the country. Sustainable energy interventions are some of the solutions to these challenges. The paper has shown that the country has resources to harness modern forms of energy from. Small-scale hydropower sites are

some of such resources that can be exploited to improve on national energy supply generally and in particular to improve on rural electrification.

This study has shown that Malawi has considerable potential for generation of SHP systems. Potential sites on rivers and existing dams are numerous and very few of them have been exploited so far. Excluding dams, the paper estimates the proven potential for SHP to be over 7.6 MW. Considering the fact that some sites have not yet been assessed, SHP is arguably one of the important renewable energy resources for Malawi. However, there is need to update the information on technical characteristics of the already identified potential sites because the hydropower potential can be affected by the impacts of environmental degradation and climate change which are already prevailing in the country.

The current inventory of small-scale hydropower systems in Malawi is relatively small, despite availability of potential. The installed capacity is estimated to be 5791 kW of which 5433 kW (which includes 4500 kW Wovwe Plant) is available. Most of the installed systems were designed to supply electricity for the community by missionaries, tea factories and nongovernmental organisations. ESCOM has two units of which one (Wovwe Plant) supplies power to the grid. Most of the installed systems are not functioning due to general engineering problems coupled with lack of maintenance and spare parts. In general, the level of utilisation of SHP is low.

Despite the fact that the SHP technology is quite mature, there are challenges towards its popularisation in Malawi. The challenges as discussed in the paper are limitations in economic, technical and awareness of the technology. There are also opportunities towards development of the technology in the country.

Private sector involvement in decentralised energy supply business is considered as one of the important factor for the popularisation of renewable energy technologies in a country. In this respect, it is recommended that Malawi should accelerate the process of developing a Feed-in-Tariff which should be used to encourage investments into SHP generation and other renewable energy systems. Further, in order to attract large investors who can develop hydropower of up to small hydropower category, the country should also come up with a Standard Power Purchase Agreement. Although the new Energy Laws allows private power generation to invest as Independent Power Producers, it is also necessary that special information dissemination on SHP generation services should be accessed through institutionalized arrangements.

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